PHY 102 - General Physics II

by

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Overview:

-Conductors and currents: electric current, resistors and resistance

-Electric power

Introduction

Electricity (into two groups)

1. Static electricity (usually produced by friction e.g rubbing an ebonite rod with fur)
2. Current electricity (branch of electricity that deals with continous flow of electrons generated by a **chemical** or generator)

Carriers of electric charges

Material	Charge carriers
Metals	Electrons (-)
Gases	Electrons and ions
Semiconductors	Electrons(-) and holes (+)
Liquid	Ions (+ and -)

Materials

Materials are classified basically into three:

- Conductors
- Semiconductors
- Insulators

Current and resistance

An **electric current** is a flow of electric charge or the quantity of charges that flows in a circuit or conductor per second.

$$q = It \quad , \quad i\,(A) = \frac{dq}{dt}\ (coulomb\ per\ second) \quad , \quad q = \int_{t_1}^{t_2} i dt$$

In electric circuits this charge is often carried by moving electrons in a wire e,g in metals

Electric current can also be carried by:

- ions in an electrolyte (NaCl Solution, Conc or Dilute H_2SO_4)

`- both ions and electrons such as in an ionised gas (plasma).

Types of electric current

1. Alternating current (A.C)

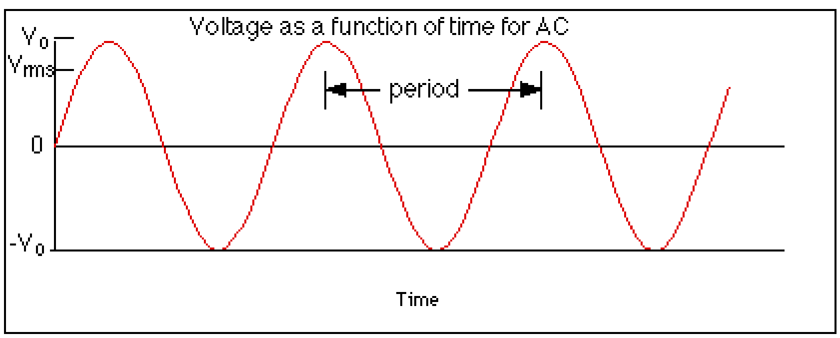
   In alternating current (AC) systems, the movement of electric charge periodically reverses direction.

   AC is the form of electric power most commonly delivered to *businesses and residences.*

   Audio and radio signals carried on electrical wires are also examples of alternating current

   The usual waveform of an AC power circuit is a sine wave.

   We can also have triangular or square waves, saw-tooth etc. Direct current (D.C)



   Direct current (D.C

2. In contrast, direct current (DC) is the *unidirectional flow (One way)* of electric charge, or a system in which the movement of electric charge is in one direction only.

   Direct current is produced by sources such as batteries, thermocouples, solar cells, and dynamo type.

   Voltage is usually constant.

   Direct current may flow in a conductor such as a wire, semiconductors, insulators, or even through a vacuum as in electron or ion beams.

The SI unit for measuring an electric current is the ampere, which is the flow of electric charge across a surface at the rate of one coulomb per second.

Electric current is measured using a device called an ammeter.

Electric current

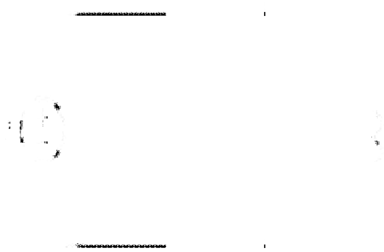


Figure 1: A simple electric circuit, where current is represented by the letter *i*.

Ohm's law

The current (I) passing through a wire is directly proportional to the potential difference (V) between the two ends provided the temperature of the wire. remains constant

V α I

The relationship between the voltage (V), resistance (R), and current (I) is V=IR; this is known as Ohm's law

Graph of V against I is linear

$$\boldsymbol{Slope = \frac{\Delta V}{\Delta I} = Resistance\ of\ the\ wire\ (ohm\ \cap\ )}$$

<u>Limitations of Ohm's law</u>

1. **The *<u>temperature must be constant</u>***
2. **The wire must *<u>not be under tension</u>***

Currents in small values can be measured in μA (microamperes), mA (milliamperes)

$1\mu A = 10^{-6}$ A , $1\ kA = 10^{3}$ A , $1mA = 10^{-3}$ A

The potential difference is measured in Volts using *voltmeter*. The *<u>voltmeter</u>* must be connected *<u>in parallel</u>* while *<u>ammeter in series</u>* to the material in which the pd or current is to be measured

$1\mu V = 10^{-6}$ V , $1\ kV = 10^{3}$ V , $1mV = 10^{-3}$ V

Note: $E\ (electrical\ energy) = Q(quantity\ of\ charges) \times V(p.d),\ V = \frac{E}{Q}$ (J/C)

1 Volt = 1 Joule/coulomb

Electrical resistance

Voltage can be thought of as the pressure pushing charges along a conductor while the electrical Resistance of a conductor is a measure of how difficult it is to push the charges along.

Using the flow analogy, electrical resistance is similar to friction.

For water flowing through a pipe, a *long narrow pipe provides more resistance* to the flow than does a short fat pipe. The same applies for flowing currents: long thin wires provide more resistance than do short thick wires.

The resistance (R) of a material depends on its length, cross-sectional area, and the resistivity (the Greek letter rho), a number that depends on the material:

$R = \rho L / A$ Resistance is measured in ohms, Ω.

The resistivity and conductivity are inversely related. Good conductors have low resistivity, while poor conductors (insulators) have resistivities that can be 20 orders of magnitude larger.

$Resistivity \quad \rho = \frac{1}{\sigma}$ Unit = Ωm (ohm-meter) where σ = conductivity ($\Omega^{-1}m^{-1}$)

Resistance also depends on temperature, *usually increases as the temperature increases* i.e a function of temperature.

This is reflected in the equations:

$\rho = \rho_0 [1 + \alpha (T - T_0)]$ and, equivalently, $R = R_0 [1 + \alpha (T - T_0)]$

At low temperatures some materials, known as superconductors, have no resistance at all. Resistance in wires produces a loss of energy (usually in the form of heat), so materials with no resistance produce no energy loss when currents pass through them.

Ohm's Law

In many materials, the voltage and resistance are connected by Ohm's Law:

Ohm's Law : V = IR

The connection between voltage and resistance can be more complicated in some materials.These materials are called non-ohmic. We'll focus mainly on ohmic materials for now, those obeying Ohm's Law.

Resistors

It is an electrical conductor that forms a resistance to the free flow of electric current.

It is made of wire, carbon or graphite wound round an insulator with the wire ends as the terminals.

Resistance = opposition to the flow of current by a conductor or in a circuit. Unit : Ohm (Ω)

Resistors (types)

1. **Wire-wound resistors (Δr reduces as T increases)**
2. **Fixed resistors**
3. **Variable resistors**
4. **Resistance box**

Factors that affect the resistance of a wire

(1) Length of the wire (l)
(2) Cross sectional area of the wire (A)
(3) Temperature
(4) Nature of the material (Ge, Si or tungsten wire)

$R = \rho L / A$ Resistance is measured in ohms, Ω.

Problem 1

A copper wire has a length of 160 m and a diameter of 1.00 mm. If the wire is connected to a 1.5-volt battery, how much current flows through the wire? (For copper, $\rho = 1.72 \times 10^{-8}\ \Omega\ m$)

Solution

$R = \rho L / A$ Resistance is measured in ohms, Ω.

L =1.60 m. V=1.5 V

For copper, $\rho = 1.72 \times 10^{-8}\ \Omega\ m$

The cross-sectional area of the wire

$A = \pi r^2 = \pi (0.0005)^2 = 7.85 \times 10^{-7}\ m^2$

The resistance , R of the wire is then

$R = \rho L / A = (1.72 \times 10^{-8}) (160) / (7.85 \times 10^{-7}) = 3.50\ \Omega$

The current can now be found from Ohm's Law:

I = V / R = 1.5 / 3.5 = 0.428 A

Connection of resistors

1. Series circuits

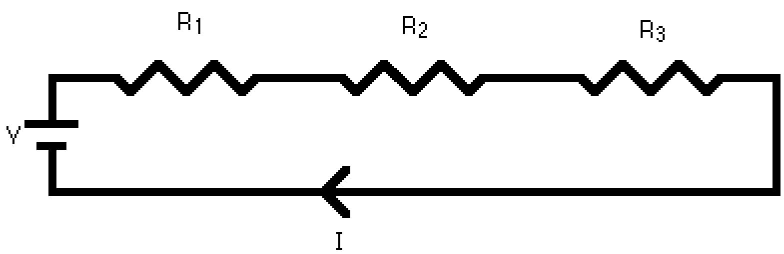
A series circuit is a circuit in which resistors are arranged in a chain, so the current has only one path to take. The current is the same through each resistor. The total resistance of the circuit is found by simply adding up the resistance values of the individual resistors:

The equivalent resistance (R_{eqv}) of resistors in series : $R = R_1 + R_2 + R_3 + \ldots$ (same current I passes through)

$$V = IR_{eqv}, \quad V_1 = I_2R_2, \qquad V_2 = I_2R_2 \ , V_3 = I_3R_3$$

but $I = I_1 = I_2 = I_3$ Hence, $I R = I R_1 + I R_2 + I R_3 = I (R_1 = R_2 + R_3)$

The equivalent Resistance $R_{eqv} = R_1 + R_2 + R_3$



A series circuit is shown in the diagram above. The current flows through each resistor in turn. If the values of the three resistors are:

$R_1 = 8\ \Omega$, $R_2 = 8\ \Omega$, and $R_3 = 4\ \Omega$, the total resistance is $8 + 8 + 4 = 20\ \Omega$.

With a 10 V battery, by V = I R the total current in the circuit is:

I = V / R = 10 / 20 = 0.5 A. The current through each resistor would be 0.5 A.

2. Parallel circuits

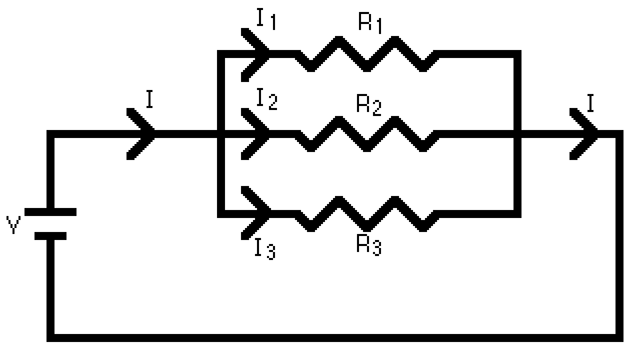
A parallel circuit is a circuit in which the resistors are arranged with *their heads* connected together, and their tails connected together.

The total resistance of a set of resistors in parallel is found by adding up the reciprocals of the resistance values, and then taking the reciprocal of the total:

(same P.d) $V = V_1 = V_2 = V_3$ $V = IR,\ I_1 = \frac{V}{R_1}\ , I_2 = \frac{V}{R_2}\ , I_3 = \frac{V}{R_3}$

$$I = \frac{v}{R} = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Hence, the equivalent resistance of resistors in parallel: $1 / R = 1 / R_1 + 1 / R_2 + 1 / R_3 + \ldots$



A parallel circuit is shown in the diagram above. In this case the current supplied by the battery splits up, and the amount going through each resistor depends on the resistance. If the values of the three resistors are:

$R_1 = 8\ \Omega$, $R_2 = 8\ \Omega$, and $R_3 = 4\ \Omega$, the total resistance is found by:

$1 / R = 1 / 8 + 1 / 8 + 1 / 4 = 1 / 2$. This gives $R = 2\ \Omega$.

With a 10 V battery, by V = I R the total current in the circuit is: I = V / R = 10 / 2 = 5 A.

The individual currents can also be found using I = V / R. The voltage across each resistor is 10 V, so:

$I_1 = 10 / 8 = 1.25$ A
$I_2 = 10 / 8 = 1.25$ A
$I_3 = 10 / 4 = 2.5$ A

Note that:

for resistors in series, the current is the same for each resistor while

for parallel, the voltage is the same for each one.

Problem 2

Three cells of emf 3 V and internal resistance of 0.6 are connected in parallel in order to reduce the potential difference across the circuit. Calculate the effective internal resistance of the cell?

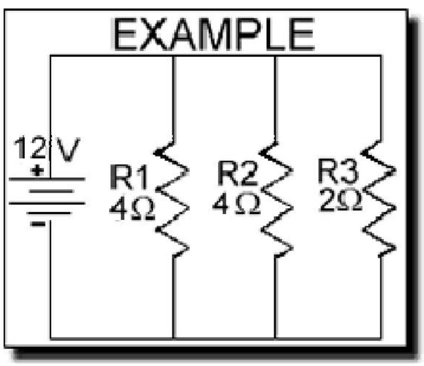
Solution

$$r_1 = r_2 = r_3 = 0.6\ ohms$$

$$\frac{1}{r_{eff}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{1+1+1}{0.6} = \frac{3}{0.6}\ \ hence\ \ \ r_{eff} = \frac{0.6}{3} = 0.2\ \cap$$

Problem 3

In the circuit below determine the combined resistance. Hence, calculate the current in the circuit



Solution

$$\frac{1}{r_{comb}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{1}{4} + \frac{1}{4} + \frac{1}{2}, \qquad r_{comb} = 1\Omega$$

Hence, V=IR

I=V/R= 12/1=12 A

$I_1 = 3$ A, $I_2 = 3$ A while $I_3 = 6$ A

Electric Power (P)

Power is the rate at which work is done OR The workdone per second in a conductor.

$$P = \frac{Workdone\ or\ electrical\ energy}{time\ taken} = \frac{Ivt}{t} = IV$$

Electrical energy = Quantity of electricity X potential difference = QV = It X V

It has units of Watts. 1 W = 1 J/s

Electric power is given by the equations:

$P = VI$ $P = V^2 / R$ $P = I^2 R$

The power supplied to a circuit by a battery is calculated using P = VI , Unit : Watt (W)

1000 Watts = 1 KW

Batteries and power supplies supply power to a circuit, and this power is used up by motors as well or by anything that has resistance.

The power dissipated in a resistor goes into heating the resistor; this is known as Joule heating.

In many cases, *Joule heating is wasted energy.* E.g in an *electric heater.*

Joule's law of electrical heating

The law states that the **heat energy (H)** obtained in electrical wire is *directly proportional* to:

1. R if I and t are constant
2. I if R and t are constant
3. T if R and I are constant

Hence, $H = I^2Rt$

In electric company,

bills generated is not for power but for energy (using units of kilowatt-hours).

1 kW-h = 3.6 x 10^6 J

Cost = (Power rating in kW) x (number of hours it's running) x (cost per kW-h)

An example...if a 100 W light bulb is on for two hours each day, and energy costs $0.10 per kW-h, how much does it cost to run the bulb for a month?

Cost = 0.1 kW x 60 hours x $0.1/kW-h = $0.6, or 60 cents.

Thank you for listening

See you later